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MEMORANDUM REPORT BRL-MR-3667

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# COMPUTER-AIDED TECHNIQUES FOR SURVIVABILITY/LETHALITY MODELING


PAUL H. DEITZ




FEBRUARY 1988



U.S. ARMY LABORATORY COMMAND

**BALLISTIC RESEARCH LABORATORY**

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Over the past five years the Ballistic Research Laboratory (BRL) has established a powerful set of computer-based, analytic tools particularly oriented to high-resolution weapons engineering. This environment reflects the following major characteristics:

- o Establishment of machine-independent UNIX operating system environment which combines both Berkeley 4.2 and AT&T System V capabilities.
- o Generation of an advanced solid-geometric modeler by means of which complex military target descriptions can be accurately and quickly modeled (including interior detail) together with material properties for supporting high-resolution weapons simulations.
- o A flexible library of raycasting subroutines which can interrogate the three-dimensional geometry built in the editor. This powerful interface makes


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possible simulation of arbitrary bullet trajectories, ricochet, optical reflection, animation, synthetic aperture radar calculations, neutron transport, etc.

- The development of many specific weapons analysis tools which include:

| | |
|---|---|
| -Neutron Transport | -Ballistic Penetration |
| -Survivability/Lethality | -Battle Repair/Parts Stockpiles |
| -Weights/Moments of Inertia | -Infrared Signature Predictions |
| -Radar Cross Section | -Synthetic Aperture Radar |
| -Acoustic Signatures | -Optical Target Designation |
| -Stealth Techniques | -High-Energy Laser Damage |

- A link from the BRL solid geometry into a commercial finite-element preprocessor (PATRAN[TM]) which can be used to generate 3-D surface and volume meshes. In turn these meshes can be linked to heat flow, static and dynamic stress, and acoustic simulations.

By way of background, nearly all weapons analyses require three-dimensional geometric (shape) and material (attribute) properties as principal input functions. Commonly in fact, the lack of critical target system shape or design information represents the limiting factor in the ability to predict system characteristics.

For many years combined geometric/attribute information has been utilized by the BRL to support vulnerability/survivability and neutron transport studies. Recently modern computer-aided techniques have been applied to enhance the speed and accuracy for the generation of what are known as target descriptions. In the field of Computer-Aided Design (CAD) this process is called solid modeling and represents a special class of rigorous methods.

However the utility of solid modeling extends far beyond supporting vulnerability and nuclear affects modeling. In fact essentially every high-resolution weapons analysis can be supported by the generalized methods used. The BRL has linked solid modeling applications to weights and moments calculations, finite-element mesh generation, and structural and signature analyses. Extant signature methods include the ability to model bistatic optical illumination, IR thermal imagery, acoustic signatures, and many millimetre wave/centimeter wave (MMW/CMW) applications including synthetic aperture radar (SAR) and various vehicle surface topology "filters" which can be used to derive shape features which dominate radar backscatter. Such high-resolution, predictive-signature techniques provide critical input to target recognition studies, smart munition simulations, and interpretation of battlefield intelligence. They in fact provide an unprecedented capability to perform survivability and vulnerability analyses with the breadth and detail to yield true system perspective. And because of the UNIX environment within which these techniques are supported, these tools have been ported over many computer architectures and to many government and non-government users.

In this paper an overview will be given of the geometric modeling techniques which form the core of these tools. Examples of the way in which geometry/attribute data are interrogated together with a wide variety of weapons analyses will be presented. This paper will also provide the context for two subsequent presentations which will examine a new stochastic vulnerability code (A. Ozolins) and a predictive radar scattering code (R. Shnidman).

TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS

# I. INTRODUCTION

The vulnerability of a combat system is an assessment of its susceptibility to damage, given a specific encounter with a particular threat. By contrast, system survivability can be taken to be the examination of all performance parameters which affect its availability to perform an assigned mission. Thus survivability subsumes vulnerability with the addition of many other factors. Some of the system parameters contributing to survivability are:

- Mobility;
- Agility;
- NBC Protection;
- Detection Probabilities ~~in the regions of:~~ (
  - Magnetic;
  - Acoustic;
  - Optical;
  - ~~IR~~ infrared; and
  - ~~CMW/MMW~~ centimeter waves/millimeter waves);
- Conventional Vulnerability.

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The theme of this Symposium is "The Total System Approach to Combat Survivability." Such an approach, therefore, requires a broad set of analytic tools which permit a system to be analyzed from many aspects with a consistent set of inputs.

The aim of this paper is to describe a high-resolution modeling environment which supports the symposium theme; this environment is being rapidly expanded and is characterized by the following major features:

1) A powerful geometric modeling environment;
2) A set of flexible routines for geometric interrogation;
3) A set of analytic modules which extend across many of the disciplines which are a theme of this conference;
4) A link to Finite Element Mesh (FEM) generation; and
5) Support of above tools in a consistent, portable UNIX environment. (KR)

Due to space limitations, this paper will avoid detail but will include references to other sources where further information can be found.

## II. GEOMETRIC AND ATTRIBUTE MODELING

In order to support any analytic model, files of inputs must invariably be assembled. In general, files may consist of information describing the system geometric configuration, the material of which it is constituted, characterization of components to damage, or descriptions of system operational parts in terms of redundancy or lack thereof.

Often, the most difficult kind of input to assemble is geometric. This is particularly so for the kinds of analyses with which we are concerned for supporting survivability studies. Not only must an analytic framework be developed which is capable of full surface descriptions of all components, both inside and out, but all parts of three-dimensional space must be fully defined as to material makeup. The kinds of material properties associated with geometry depend upon the analyses to be run later. Thus, the attribute data base associated with geometry must be extensible.

Geometric modeling systems capable of supporting this level of rigorous modeling are termed solid geometric. The BRL has developed its own solid geometry system called GED (for Graphics EDitor). This system has been a production tool for vulnerability analysts for more than half a decade,[1-3] during which time many enhancements have been made. Recent improvements include special commands to simplify the building of armors associated with armored fighting vehicles (AFVs) and the addition of device-independent software to ease the porting of GED to new environments.[4]

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[1] P. H. Deitz, "Solid Modeling at the US Army Ballistic Research Laboratory", Proceedings of the 3rd NCGA Conference, 13-16 June 1982, Volume 2, pp. 949-960.

[2] M. J. Muuss, K. A. Applin, R. J. Suckling, G. S. Moss, E. P. Weaver and C. Stanley, "GED: An Interactive Solid Modeling System for Vulnerability Analysis", BRL Technical Report ARBRL-TR-02480, NTIS AD# A-126-657, March 1983.

[3] P. H. Deitz, "Solid Geometric Modeling - the Key to Improved Materiel Acquisition from Concept to Deployment", in the *"Proceedings of the XXII" "Annual Meeting of the Army Operations Research Symposium"*, 3-5 October 1983, Ft. Lee, VA, pp. 4-243 to 4-269.

[4] M. J. Muuss, "Understanding the Preparation and Analysis of Solid Geometric Models", in *"State of the Art in Computer Graphics"* (Springer Verlag, 1986), edited by Rogers & Earnshaw.

Some appreciation of the magnitude of the geometric modeling task can be gained by examining Figure 1. This is a representation of just part of the target description associated with the M1 main battle tank. That description now includes over 5000 separate components together with all critical wires and hydraulic lines.

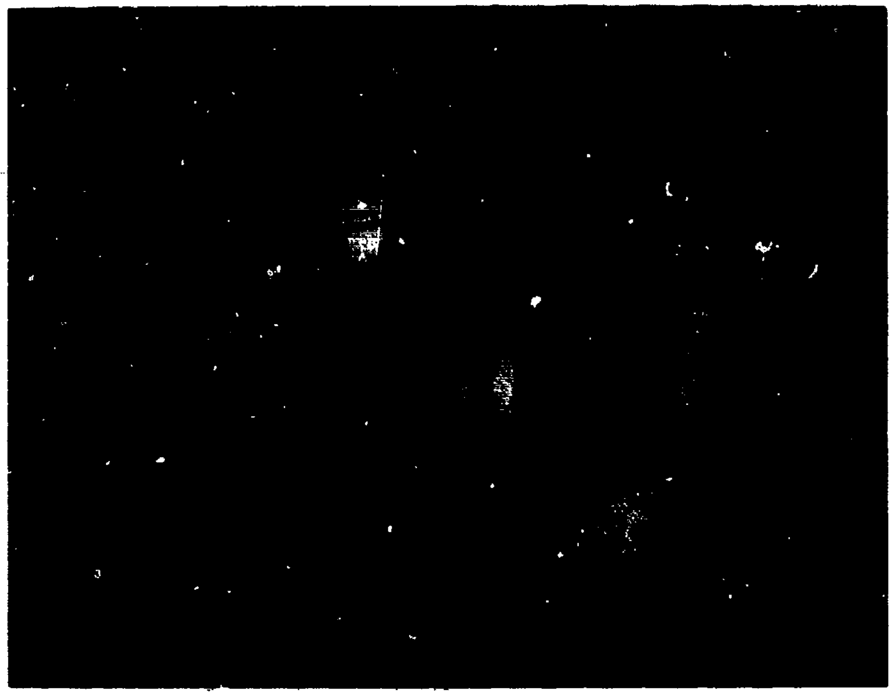

Figure 1. A portion of the interior detail of the current M1A1 target description in the region of the turret basket. The nine rods on a regular grid represent possible shaped-charge jet paths through the components. The transparent spall cone shows the domain within which behind-armor debris is likely to be generated for the hit point in question. See Reference 24 for details on how this geometry is being analyzed.

Now in beta test is a significant extension to GED which makes it possible to merge spline representations together with previously supported simpler shapes. These extensions are due to work performed under a DARPA contract (monitored by the BRL) with the University of Utah; the advanced modeling environment is called "Alpha_1" and it supports the building of complex shapes by a user-configurable LISP interface which has many powerful features.[5-7]

An example of the extended GED capability can be seen by contrasting Figures 2 and 3. Figure 2 shows an image of an M48 tank as it has been described for many years. Compound surfaces, such as the glacis and turret, have been approximated using a series of triangular facets. This approach is acceptable for some applications, but in the case of active optical illumination (to name but one exception), yields artifacts which are based on the geometric approximations used to model the true target surface.

Figure 2. An image of an M48 tank as it has been described for many years. Compound surfaces, such as the glacis and turret, have been approximated using a series of triangular facets.

Figure 3 shows the same vehicle in which the turret has been replaced by a spline entity.[8] The surface can be seen to be entirely smooth; using such techniques, complex geometries can be modeled with great accuracy when required by a particular application.

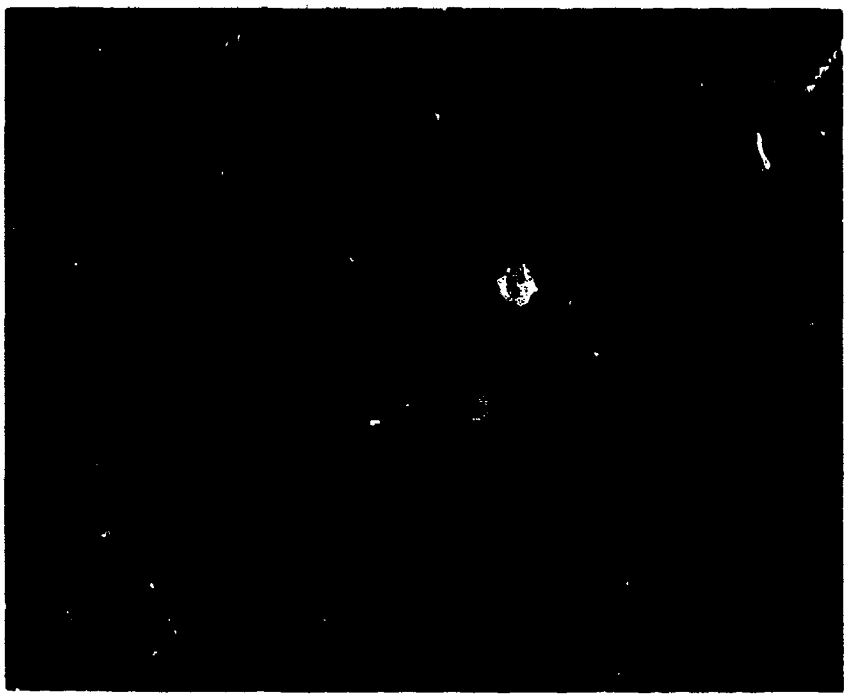

Figure 3. The same M48 target description used in Fig. 2 except that the turret has been replaced by a spline entity[8]. The surface can be seen to be entirely smooth; using such techniques, complex geometries can be modeled with great accuracy when required by a particular application.

Although geometry is the most prominent as well as the most difficult input to prepare for survivability modeling, there are others worth noting.

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5 R. F. Riesenfeld, E. Cohen and T. Lyche, "Discrete B-splines and Subdivision Techniques in Computer Aided Geometric Design and Computer Graphics", *"Computer Graphics and Image Processing," "Vol. 14," "No. 2,"* October 1980, pp. 87-111.

6 E. Cohen, "Mathematical Tools for a Modelers Workbench", *IEEE Computer Graphics and Applications*, October 1983.

7 R. F. Riesenfeld, "A View of Spline-Based Solid Modelling", *Proceedings of Autofact 5, Computer and Automated Systems Association of SME*, 1983.

8 Private communication with P. R. Stay.

Central to the assessment of the vulnerability of AFVs is a criticality analysis. This task identifies all components which contribute to either the fire-power or mobility functioning of the system. Each system is organized into a logical unit which indicates component redundancy (parallel functioning) or non-redundancy (serial functioning). Such layouts are referred to as

deactivation diagrams. In the past such diagrams had to be hand-drawn by a vulnerability analyst; subsequently the mathematical equivalency of the diagram had to be manually derived. This was an error-prone task which had to be repeated for dozens of subsystems.

A special language, graphical display capability and equation compiler was developed to automate this process.[9] An example of a deactivation diagram for an AFV generated by this technique is shown in Figure 4.

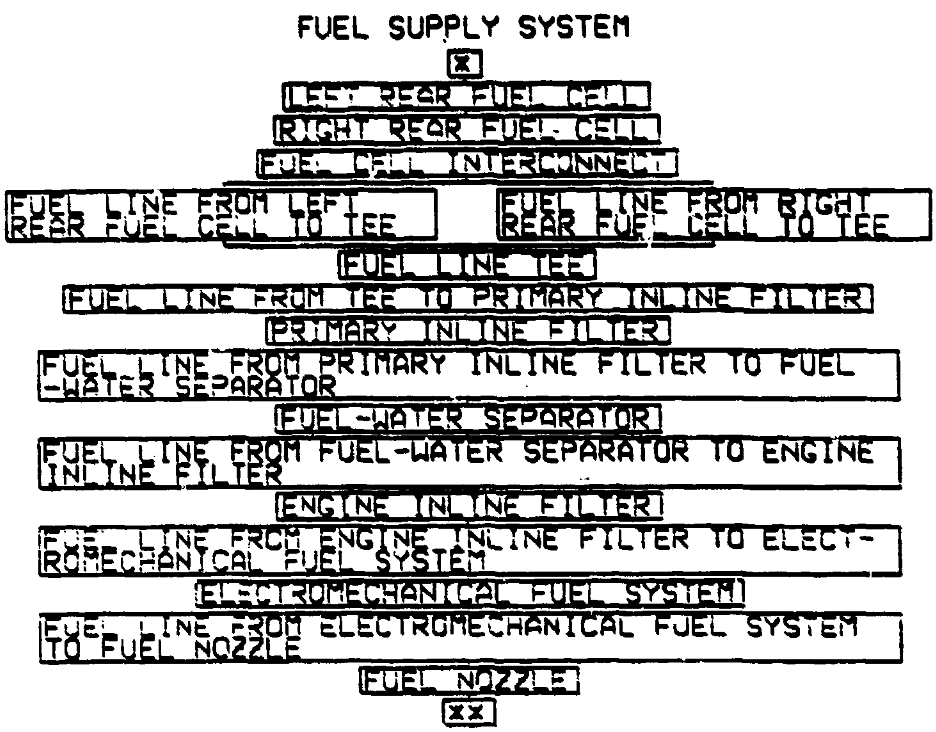


Figure 4. A computer-generated deactivation diagram showing the logical functioning of the Fuel Supply System for an AFV. Such diagrams are used to describe components which are critical to performing fire-power or mobility functions. Components shown in parallel have functional redundancy; those in series do not.

[9] The program which supports this function is called ICE for Interactive Criticality Estimator, written by G. S. Moss.

## III. GEOMETRIC AND ATTRIBUTE INTERROGATION

As noted above, in order for applications codes to function, they need critical input about system geometry, material constituency, and other properties. The principal technique (but by no means the only one) for extracting geometric information about a system is to pass mathematical rays through the representation of target geometry. Raycasting is used for many subsequent applications including bullet trajectories, light rays, and neutron travel. As the ray traverses the target description, the material (steel, air, fuel, etc.) is known at every point along the path. Also the three-space position of the ray is calculated as it enters and leaves each surface. Optionally the surface normals and three-dimensional curvatures can be calculated at each surface of intersection.

In the past, raycasting support has been supplied by a code known as GIFT.[10] It is a monolithic code, written in FORTRAN, and can support only single-CPU, batch processing.

A new code called RT (for Ray Trace)[4] has been in extensive beta testing at BRL and elsewhere. It will become the supported ray casting tool at BRL and has the following properties:

- The ability to fire rays in arbitrary directions from arbitrary points
- Support of batch and interactive control of ray paths to implement, naturally, reflection, refraction, and fragmenting into multiple subsidiary rays
- A code structure which facilitates the addition of new classes or shape (primitive) structures to the data base
- The ability to support multiple-CPU (true parallel) computation.

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[10] G. G. Kuehl, L. W. Bain Jr. and M. M. Reisinger, "The GIFT Code User Manual; Volume II, The Output Options (U)", US Army ARRADCOM Report No. 02189, AD #A078364 September 1979. GIFT stands for Geometric Information For Targets.

Raycasting, together with a lighting model, was used to derive the images shown in Figures 1-3.

Although raycasting is by far the most-used method of extracting geometry from target descriptions, other techniques exist. One important one involves the transformation of a solid geometric file into a Finite-Element Mesh (FEM). Numerous analytic models exist which use FEM files; included in this class are various static and dynamic structural codes. Such codes can calculate various stress environments for applied static loads, vibrational states of structures when driven by periodic or impulsive loading, and also provide the environment for the calculation of heat flow.

In order to exploit analysis methods which require mesh generation, a commercial FEM pre- and post-processor program called PATRAN [TM][11] has been purchased and installed in the BRL environment. Although PATRAN has its own geometric modeler, in order to avoid the high-overhead task of regenerating existing geometry in yet another format, a program has been written[12] to translate GED files into the PATRAN format.

## IV. APPLICATIONS SUPPORTED BY GED GEOMETRY

The key to analysis of total system survivability is a broad set of tools, each capable of examining one significant part of the problem. In this section we briefly list and annotate the codes which are supported by the BRL modeling environment.

- Weights & Moments-of-Inertia: This code calculates system weights (total or any subset) as well as moments-of-inertia. The latter calculation can be used, for example, to gauge the effect of additive turret armor on the performance of the fire control system. See Reference 3.

[11] PATRAN is a product of PDA Engineering, Santa Ana, CA.

[12] The GED-to-PATRAN translation program is called GEDPAT and was written by G. S. Moss.

- **Ballistic Modeling:** This single heading is used to annotate a series of models used for assessing the vulnerability of ground and air targets to all manner of bullets and/or lethal fragments. To summarize a large suite of analytic codes in this area, capabilities exists to:

  + Calculate penetration into structures (such as ballistic hulls and turrets) and the magnitude of residual penetration.[13-16]

  + Calculate aggregate kill levels (Mobility, Firepower, Catastrophic for ground vehicles;[17] various levels of Mission Aborts for aircraft) based on lumped parameters.[18]

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[13] R. DiPersio, J. Simon and A. Merendino, "Penetration of Shaped Charge Jets into Metallic Targets", BRL Report No. 1296, September 1965.

[14] C. L. Grabarek, "Penetration of Armor by Steel and High Density Penetrators", BRL Memorandum Report No. 2134, NTIS AD# 518394C, October 1971.

[15] L. Herr and C. L. Grabarek, "Ballistic Performance and Beyond Armor Data for Rods Impacting Steel Armor Plates", BRL Memorandum Report No. 2575, NTIS AD# B009979C, January 1976.

[16] M. S. Saccucci, L. L. Crawford and R. Shnidman, "An Empirical Behind-Armor Debris Model for Explosively Formed Penetrators", BRL Technical Report BRL-TR-2607, November 1984, (Confidential).

[17] C. L. Nail, E. Jackson and T. E. Beardon, "Vulnerability Analysis Methodology Program (VAMP) A Combined Compartment-Kill Vulnerability Model", Computer Sciences Corporation Technical Manual CSC TR-79-5585, October 1979.

[18] D. L. Dickinson, C. Gillespie, M. Lentz, J. Burk and J. Young (Anti-Air/Air Targets Vulnerability Working Group), "COVART II - A Simulation Program for Computation of Vulnerable Areas and Repair Times - User Manual", JTCG/ME-84-3, 19 September 1985.

+ Calculate similar kill levels using point-burst methodologies (main penetrator and spall damage is explicitly analyzed).[19-22]

+ Extensions of above capabilities t assess specific parts damage and repair times.[23]

+ Extensions of above capabilities to AFVs to include a complete stochastic treatment of all principal model inputs so that probability density functions for all classes of kills are derived. This code is used chiefly to support live-fire testing and is actively under development.[24]

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[19] C. L. Nail, "Vulnerability Analysis for Surface Targets (VAST)- An Internal Point-Burst Vulnerability Assessment Model - Revision I", Computer Sciences Corporation Technical Manual CSC TR-82-5740, August 1982.

[20] F. T. Brown, D. C. Bely and D. A. Ringers, "The Simple Lethality and Vulnerability Estimator (SLAVE): User's Manual", BRL Technical Report ARBRL-TR-02282 (AD# B055277), January 1981.

[21] D. A. Ringers and F. T. Brown, "SLAVE (Simple Lethality and Vulnerability Estimator) Analyst's Guide", Technical Report ARBRL-TR-02333 (AD# B059679), June 1981.

[22] J. H. Suckling, C. G. Moore, Jr. and R. Pierson, Jr., "SIMVA; A Simplified Point Burst Vulnerability Analysis Code", BRL Memorandum Report BRL-MR-3419, December 1984.

[23] J. C. Saccenti and R. N. Schumacher, "SPARC Analysts' Methodology Handbook", BRL Technical Report ARBRL-TR-02562, April 1984.

[24] Private communication with A. Ozolins, the principal author of a the new stochastic point-burst vulnerability code called SQuASH (for Stochastic Quantitative Analysis of System Hierarchies). With this code, warhead hit location, penetration depth, behind-armor-spall fragments and component kills are all varied statistically. Among many results, this code gives the likelihood of various discrete component damage states occurring, given a single shot; it also gives the distribution of Loss-of-Function states (i.e. histograms) for Mobility, Firepower and Mobility/Firepower and the Probability-of-Kills for Catastrophic (K) Kill.

+ Blast overpressure inside an AFV due to the entry of a shaped-charge jet. An earlier approach[25] based on a method of images is currently being modified so as to benefit from rigorous raycasting together with detailed target geometry.[26]

- Neutron Transport: This code calculates the nuclear environment in and around various enclosures (including AFVs) in order to assess the effect of nuclear events on people and equipment.[27] Total radiation dose at an arbitrary location interior to the vehicle is summed by calculating leakage through all exterior regions.
- Signature: The BRL, together with other parties, has developed a number of empirical and predictive signature codes. Among these are:

  + Optical- A set of codes has been written which can simulate both specular and diffuse scattering, full-target (as in sunlight) and partial illumination (as with laser designation). Capabilities include the ability to model full and partial reflection, refraction through optical media, and animation; also multiple light sources and arbitrary beam shapes for incident radiation can be modeled.[28,29]

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[25] C. W. Heaps, "Computer Model of Blast Overpressure Internal to Armored Vehicles Due to Shaped Charge Penetration", BRL Memorandum Report BRL-MR-MR-3515, April 1986.

[26] Private communication with P. J. Hanes; this module is currently in development.

[27] W. A. Rhodes, "Development of a Code System for Determining Radiation Protection of Armored Vehicles (the VCS Code)", ORNL-TM-4664, Oak Ridge National Laboratory, Oak Ridge, TN, October 1974.

[28] P. H. Deitz, "Predictive Signature Modeling via Solid Geometry at the BRL", Proceedings of the Sixth KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 21-22 August 1984.

[29] G. S. Moss, "A Predictive Optical Signature Model", Proceedings of the Seventh KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 27-28 August 1985.

Figures 1-3 are all examples of the use of the BRL lighting model in various configurations. Yet another example of a lighting model application is shown in Figure 5. Here a target description of an M109 has been used to render a vehicle with transparent armor. The armor has been given the refractive property of glass together with a small amount of backscatter.

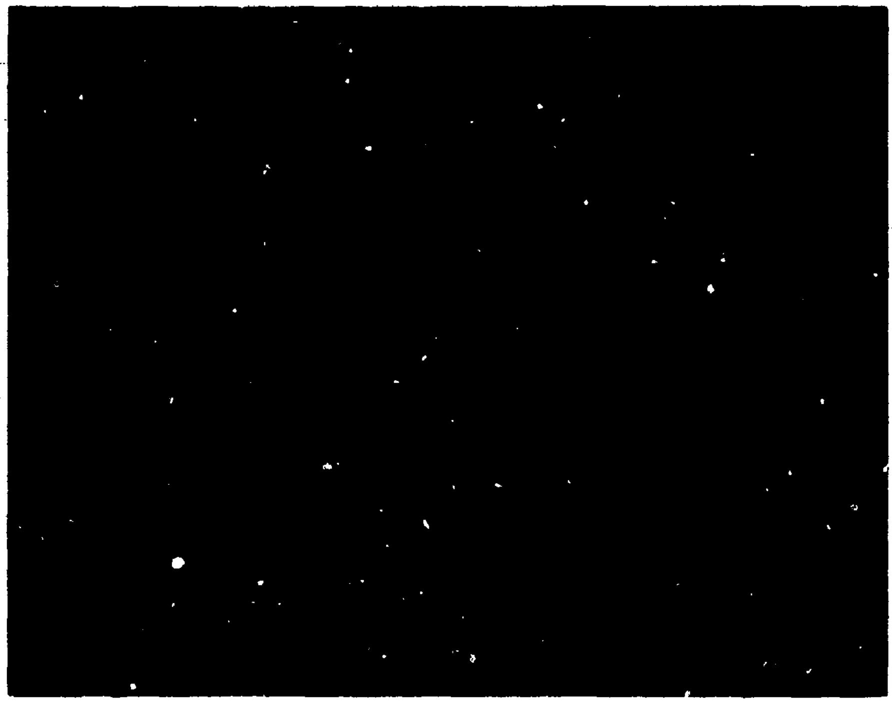

Figure 5. A target description of an M109 used to render a vehicle with transparent armor. The armor has been given the refractive property of glass together with a small amount of backscatter. This illustrates a few of the properties of the BRL lighting model[29].

+ Infrared- Two kinds of models have been developed. In the first, known target surface temperatures are married to target geometry. Viewing tools allow the target to be observed from any aspect angle, spatial resolution, and wavelength band.[30] Recent projects have resulted in two different techniques for associated measured temperatures with (external) target geometry. The first[31] is a direct automation of the technique reported in Reference 30. The second[32] uses an ancillary data structure called an octree which, when associated with the standard GED geometry, makes it possible to view high-resolution IR data bases from arbitrary aspect angles at arbitrary pass bands. Once real infrared sensor data is stored in the octree data structure, an view-angle can be chosen for interrogation.

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[30] J. R. Rapp, "A Computer Model for Estimating Infrared Sensor Response to Target and Background Thermal Emission Signatures", BRL Memorandum Report ARBRL-MR-03292, August 1983.

[31] H. J. Reed, "Infrared Signature View Independent Modeling", Eighth KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 19-21 August 1986. In this approach vehicle surface temperatures are associated directly with GED file regions, the smallest unit recognized in this geometry scheme.

[32] G. S. Moss, "3-D Infrared Signature Modeling", Eighth KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 19-21 August 1986.

An example of this method is shown in Figure 6.


Figure 6. A method of associating known temperature values with external target geometry. This technique, in addition to the standard GED geometry, uses an ancillary data structure called an octree. When used together, they make it possible to view high-resolution IR data bases from arbitrary aspect angles at arbitrary pass bands. The lower-left image was generated by intersecting the octree-encoded infrared data base with the GED T62 target description using raytracing techniques. Next to it is a rendering of the octree data structure itself, revealing the internal representation of homogeneous regions as cubes. Temperatures (color-coded across the bottom) are represented in degrees Fahrenheit.

The lower-left image was generated by intersecting the octree-encoded infrared data base with the GED T62 target description using raytracing techniques. Next to it is a rendering of the octree data structure itself, revealing the internal representation of homogeneous regions as cubes. Temperatures are represented in degrees Fahrenheit.

A second class of codes (being jointly developed by Environmental Research Institute of Michigan, ERIM) will allow for full prediction of target surface temperature based on system and environmental factors.[33]

+ Centimeter/Millimeter Radar Modeling- BRL has coupled its target geometry to a number of radar models including a code written at ERIM[28,34] which calculates synthetic aperture radar images (SAR) and radar cross sections. This code has also been adapted to support a raster mode of target illumination.[35] A scanning beam can be made to traverse the target geometry in order to calculate the monostatic return from specific scattering centers. A set of interface codes has been written which makes it possible to derive from the surface structure of GED files, a] flat plates, b] dihedral, and c] trihedral elements. These elements are described in a format compatible with the geometric inputs required by the radar codes utilized by Georgia Tech Research Institute.[36] Such an interface can reduce greatly the labor in developing such structures from scratch when the description already exists in GED.

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[33] Private communication with B. Morey of ERIM.

[34] This code is called SRIM (for Simulated Radar Image Modeling) and has been developed by I. J. LaHaie and C. Arnold of ERIM.

[35] T. C. Karr, "Flexibility in Radar Backscatter Simulation", Eighth KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 19-21 August 1986.

[36] Private communication with G. J. Bradley of Georgia Tech Research Institute; the GTRI radar code is called CROSS.

These radar scattering elements are also compatible with a separate code developed at BRL to support smart munition modeling.[37]

Yet another link is being forged to a Northrop SAR model called SARSIM (for Synthetic Aperture Radar Simulation).[38] This model uses faceted approximations to the surface geometry; current efforts are focussed on extracting such data structures from GED files using the RT code.

+ Acoustic- As noted above, structural modes of oscillation can be calculated in a FEM environment. This provides a key input for acoustic signature prediction.[39] During the past year, a hull structure from a concept vehicle system (Mobile Protected Gun System) was converted from a GED to a PATRAN format, meshed, and then processed using a PATRAN stress module. The first 20 vibrational frequencies of the hull were calculated.[40]

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[37] J. Lacetera, "Deterministic Modeling of Tank Targets for MMW Radar Systems", *Sixth KRC Symposium on Ground Vehicle Signatures*, Houghton, MI, 21-22 August 1984.

[38] J. V. Geaga, "Synthetic Aperture Radar Target and Terrain Simulator", Northrop Research & Technology Center Report No. 86-4R, December 5, 1985.

[39] Acoustic modes of oscillation can be computing using the standard PATRAN module.

[40] Private communication with E. F. Quigley.

- **High-Energy Laser Damage**: A set of codes has been developed to assess the effects of high-energy laser beams against ground and air targets.[41-45]

  Variable beam sizes and dwell times are utilized. Various damage criteria are calculated including general (out-of-band) surface and structural damage, out-of-band (surface) damage to optical components, and in-band damage to optical systems and sensors.

- **High Power Microwave (HPM)**: Codes are being developed to assess the microwave vulnerability of various air and ground systems.[46] A target description will be interfaced with the selected weapon-target interaction code and the HPM damage and vulnerability database to give probability of kill. This code will permit evaluation of HPM interactions with targets of interest for component failure modes and terminal effects through circuit failure analyses. Also the effects of hardening schemes can be determined.

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[41] P. S. Raglin, J. T. Klopcic and J. E.Kammerer, "Laser Induced Damage to Aircraft Components, A Final Data Reduction and a Correlation Methodology", BRL-MR-2914, April 1977 (SECRET).

[42] J. Kaplan and J. Dawkins, "CW Laser Penetration of Aluminum at 3.8 and 10.6 Microns", BRL-CR-437, September 1980 (CONFIDENTIAL).

[43] J. Kaplan and J. Dawkins, "CW Laser Penetration of Ceramics and Glasses at 3.8 and 10.6 Microns", BRL-CR-439, September 1980 (CONFIDENTIAL).

[44] G. Gunn and P. Manzo, "Semi-Empirical Fits to 10.6 Micron Pulsed Laser Effects on Aluminum", BRL-CR-488, August 1982 (CONFIDENTIAL).

[45] M. Boriack and P. Manzo, "Semi-Empirical Fits to 10.6 Micron Pulsed Laser Effects on Fiberglass, Ceramics and Glasses", BRL-CR-489, August 1982, (CONFIDENTIAL).

[46] The MIVAC (for Microwave Vulnerability Assessment Code) is being developed under contract to the BRL by R. E. O'Connor, SPARTA, Inc., Huntsville, AL, (Contr. DAAA115-85-C-0113).

- Structural Analyses: The ADINA[47] FEM code is being used to investigate the response of military systems to nuclear blast and HE blast loading and to nonperforating ballistic impact loading. The EPIC-2 code[48] is being used to determine the loading history used in the ADINA analyses of nonperforating ballistic impact. Pre- and post-processing of the analyses are accomplished using PATRAN.

This completes a summary of codes which, in a broad sense, all relate to system survivability. With these tools it is possible to calculate more quickly and accurately than ever highly detailed, quantitative estimates of system performance. The kinds of metrics reviewed in this paper can be referred to as item-level measures of performance.

However, as our ability to generate detailed measures of performance has improved, our ability to relate these factors rigorously to battlefield effectiveness has not kept pace. Discussed elsewhere,[49] at issue is the way in which the Army specifies its needs for new systems as well as the specific requirements for those systems. It can be asserted that current Army procedures are overly dependent on subjective input for:

- Definition of general item requirements.
- Effectiveness criteria by means of which to focus the technical mix of system performance characteristics.
- Appropriate quantitative analyses for some aspects of system performance. Since the system design goals are often not well defined or quantitatively specified, it can be difficult to identify crucial design aspects which ought to be the focus of principal resources.

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[47] ADINA is a product of ADINA Engineering, Inc., Watertown, MA.

[48] EPIC-2 is a product of Honeywell, Inc., Hopkins, MN.

[49] P. H. Deitz, "The Future of Army Item-Level Modeling", in the *Proceedings of the XXIV Annual Meeting of the Army Operations Research Symposium*, 8-10 October 1985, Ft. Lee, VA.

These are all issues with which the OR/SA community must struggle over the next years.

## V. COMPUTER ENVIRONMENT

It would be premature to close a paper dealing with analysis tools without some recognition of the philosophies and strategies which are guiding the evolution of software described in the previous sections. The BRL/VLD is now in a state of rapid flux as it moves from a single CYBER/NOS computing environment (circa. 1975) supported, essentially, by a single machine, to a uniform UNIX[50] environment supported by many dozens of machines.

The direction for exploiting UNIX was set some years ago and the reasons have been documented elsewhere.[51] In the main the BRL/VLD, like many other analytic organizations, requires a broad and varied set of computational tools. Important considerations include:

- The ability to tailor computing hardware/software environments to serve particularly well specific tasks such as the generation of high-resolution geometry or the support of large data bases.

- The ability to accommodate large numbers of users across many different computers at different locations.

- The ability to capitalize on the rapid evolution of current computing machinery towards much faster and cheaper computation.

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[50] UNIX is an Operating System (OS) owned and licensed by AT&T. For those not familiar with an OS, it is a program which coordinates and runs all of the activities of a computer. UNIX, in addition to being an OS environment, is also a large set of computer utilities that aid users in the generation, checking, and running of software.

[51] P. H. Deitz, "Modern Computer-Aided Tools for High-Resolution Weapons System Engineering", *Proceedings of the CAD/CAM Mini-Symposium, MTAG 84*, 28-29 November 1984, Seattle, WA, pp. 23-42 (Published by US Army Industrial Base Engineering Activity, Rock Island, IL).

These factors, plus the extremely high cost of software, lead to the following conclusions:

- Portability and uniformity of utility and user code across machines is highly desirble.

- Intermachine communication is crucial.

- Independence from vendor-specific hardware is highly desirable.

These were the issues upon which the choice for UNIX was made. The graphical codes (such as GED, RT, and many other utilities) are coded exclusively in C. These codes have already been ported across many machine architectures on which UNIX is the native operating system[4]. Some of the machines the codes currently run on are:

- DEC VAX-11/750, VAX-11/780
- GOULD PN6000 and PN9000 Series
- Denelcor HEP H-1000
- Alliant FX/8
- Sabre Technologies
- IRIS Silicon Graphics
- CRAY XMP
- CRAY-2

On the other hand, many of the codes described in the previous section are primarily batch oriented, written in FORTRAN, and operated mainly in the CYBER environment. However a substantial effort is now underway to restructure many of these codes. The changes may be as minimal as moving to a standard version of FORTRAN; or they may encompass a complete restructuring of the program using the C language so as to cast the code into clear, modular blocks, exploit device-independent graphical routines, and employ UNIX pipes, recursion and dynamic memory allocation capabilities.

## VI. SUMMARY

In this paper we have attempted to view the issue of total system survivability as a broad, multi-dimensional analysis problem. The many kinds of analyses that must be performed must often be supported by highly complicated databases, some of which are geometric in nature.

A powerful and generic set of tools has been discussed; these tools support many of the computations necessary to make detailed, quantitative judgements on system survivability.

## REFERENCES


1. P. H. Deitz, "Solid Modeling at the US Army Ballistic Research Laboratory", Proceedings of the 3rd NCGA Conference, 13-16 June 1982, Volume 2, pp. 949-960.

2. M. J. Muuss, K. A. Applin, R. J. Suckling, G. S. Moss, E. P. Weaver and C. Stanley, "GED: An Interactive Solid Modeling System for Vulnerability Analysis", BRL Technical Report ARBRL-TR-02480, NTIS AD# A-126-657, March 1983.

3. P. H. Deitz, "Solid Geometric Modeling - the Key to Improved Materiel Acquisition from Concept to Deployment", in the "Proceedings of the XXII Annual Meeting of the Army Operations Research Symposium", 3-5 October 1983, Ft. Lee, VA, pp. 4-243 to 4-269.

4. M. J. Muuss, "Understanding the Preparation and Analysis of Solid Geometric Models", in "State of the Art in Computer Graphics" (Springer Verlag, 1986), edited by Rogers & Earnshaw.

5. R. F. Riesenfeld, E. Cohen, and T. Lyche, "Discrete B-splines and Subdivision Techniques in Computer Aided Geometric Design and Computer Graphics", Computer Graphics and Image Processing, Vol. 14, No. 2, October 1980, pp. 87-111.

6. E. Cohen, "Mathematical Tools for a Modelers Workbench", IEEE Computer Graphics and Applications, October 1983.

7. R. F. Riesenfeld, "A View of Spline-Based Solid Modelling," Proceedings of Autofact 5, Computer and Automated Systems Association of SME, 1983.

8. Private communication with P. R. Stay.

9. The program which supports this function is called ICE, for Interactive Criticality Estimator, written by G. S. Moss.

10. G. G. Kuehl, L. W. Bain, Jr., and M. Reisinger, "The GIFT Code User Manual; Volume II, the Output Options (U)", US Army ARRADCOM Report No. 02189, AD #A078364, September 1979. GIFT stands for Geometric Information for Targets.

11. PATRAN is a product of PDA Engineering, Santa Ana, CA.

12. The GED-to-PATRAN translation program is called GEDPAT and was written by G. S. Moss.

13. R. DiPersio, J. Simon, and A. Merendino, "Penetration of Shaped Charge Jets into Metallic Targets," BRL Report No. 1296, September 1965.

14. C. L. Grabarek, "Penetration of Armor by Steel and High Density Penetrators", BRL Memorandum Report No. 2134, NTIS AD #518394C, October 1971.

## REFERENCES (Cont'd)


15. L. Herr and C. L. Grabarek, "Ballistic Performance and Beyond Armor Data for Rods Impacting Steel Armor Plates", BRL Memorandum Report No. 2575, NTIS AD# B009979C, January 1976.

16. M. S. Saccucci, L. L. Crawford and R. Shnidman, "An Empirical Behind-Armor Debris Model for Explosively Formed Penetrators", BRL Technical Report BRL-TR-2607, November 1984 (Confidential).

17. C. L. Nail, E. Jackson and T. E. Beardon, "Vulnerability Analysis Methodology Program (VAMP) A Combined Compartment-Kill Vulnerability Model", Computer Sciences Corporation Technical Manual CSC TR-79-5585, October 1979.

18. D. L. Dickinson, C. Gillespie, M. Lentz, J. Burk and J. Young (Anti-Air/Air Targets Vulnerability Working Group), "COVART II - A Simulation Program for Computation of Vulnerability Areas and Repair Times - User Manual", JTCG/ME-84-3, 19 September 1985.

19. C. L. Nail, "Vulnerability Analysis for Surface Targets (VAST) - An Internal Point-Burst Vulnerability Assessment Model - Revision I", Computer Sciences Corporation Technical Manual CSC TR-82-5740, August 1982.

20. F. T. Brown, D. C. Bely and D. A. Ringers, "The Simple Lethality and Vulnerability Estimator (SLAVE): User's Manual", BRL Technical Report ARBRL-TR-02282 (AD# B055277), January 1981.

21. D. A. Ringers and F. T. Brown, "SLAVE (Simple Lethality and Vulnerability Estimator) Analyst's Guide", Technical Report ARBRL-TR-02333 (AD# B059679), June 1981.

22. J. H. Suckling, C. G. Moore, Jr. and R. Pierson, Jr., "SIMVA; A Simplified Point Burst Vulnerability Analysis Code", BRL Memorandum Report BRL-MR-3419, December 1984.

23. J. C. Saccenti and R. N. Schumacher, "SPARC Analysts' Methodology Handbook", BRL Technical Report ARBRL-TR-02562, April 1984.

24. Private communication with A. Ozolins.

25. C. W. Heaps, "Computer Model of Blast Overpressure Internal to Armored Vehicles Due to Shaped Charge Penetration", BRL Memorandum Report BRL-MR-3515, April 1986.

26. Private communication with P. J. Hanes.

27. W. A. Rhodes, "Development of a Code System for Determining Radiation Protection of Armored Vehicles (the VCS Code)", ORNL-TM-4664, Oak Ridge National Laboratory, Oak Ridge, TN, October 1974.

REFERENCES (Cont'd)


28. P. H. Deitz, "Predictive Signature Modeling via Solid Geometry at the BRL", Proceedings of the Sixth KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 21-22 August 1984.

29. G. S. Moss, "A Predictive Optical Signature Model", Proceedings of the Seventh KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 27-28 August 1985.

30. J. R. Rapp, "A Computer Model for Estimating Infrared Sensor Response to Target and Background Thermal Emission Signatures", BRL Memorandum Report ARBRL-MR-03292, August 1983.

31. H. J. Reed, "Infrared Signature View Independent Modeling", Eighth KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 19-21 August 1986.

32. G. S. Moss, "3-D Infrared Signature Modeling", Eighth KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 19-21 August 1986.

33. Private communication with B. Morey of ERIM.

34. Code SRIM developed by I. J. LaHaie and C. Arnold of ERIM.

35. T. C. Karr, "Flexibility in Radar Backscatter Simulation", Eighth KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 19-21 August 1986.

36. Private communication with G. J. Bradley of Georgia Tech Research Institute.

37. J. Lacetera, "Deterministic Modeling of Tank Targets for MMW Radar Systems", Sixth KRC Symposium on Ground Vehicle Signatures, Houghton, MI, 21-22 August 1984.

38. J. V. Geaga, "Synthetic Aperture Radar Target and Terrain Simulator", Northrop Research & Technology Center Report No. 86-4R, December 5, 1985.

39. Acoustic modes of oscillation can be computing using the standard PATRAN module.

40. Private communication with E. F. Quigley.

41. P. S. Raglin, J. T. Klopcic and J. E. Kammerer, "Laser Induced Damage to Aircraft Components, A Final Data Reduction and a Correlation Methodology", BRL-MR-2914, April 1977 (SECRET).

42. J. Kaplan and J. Dawkins, "CW Laser Penetration of Aluminum at 3.8 and 10.6 Microns", BRL-CR-437, September 1980 (Confidential).

REFERENCES (Cont'd)


43. J. Kaplan and J. Dawkins, "CW Laser Penetration of Ceramics and Glasses at 3.8 and 10.6 Microns", BRL-CR-439, September 1980 (Confidential).

44. G. Gunn and P. Manzo, "Semi-Empirical Fits to 10.6 Micron Pulsed Laser Effects on Aluminum", BRL-CR-488, August 1982 (Confidential).

45. M. Boriack and P. Manzo, "Semi-Empirical Fits to 10.6 Micron Pulsed Laser Effects on Fiberglass, Ceramics and Glasses", BRL-CR-489, August 1982 (Confidential).

46. The MIVAC (for Microwave Vulnerability Assessment Code) is being developed under contract to the BRL by R. E. O'Connor, SPARTA, Inc., Huntsville, AL, (Contr. DAAA115-85-C-0113).

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49. P. H. Deitz, "The Future of Army Item-Level Modeling", in the Proceedings of the XXIV Annual Meeting of the Army Operations Research Symposium, 8-10 October 1985, Ft Lee, VA.

50. UNIX is an Operating System (OS) owned and licensed by AT&T.

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